Determination of Scandium in mafic and ultramafic rocks of ophiolites from Luk Ulo Complex, Karangsambung, Central Java, Indonesia

Nugroho Imam Setiawan^{1,2*}, Kardo Polarman Rajoki Silitonga¹, Fahmi Adiyatma Makkaratte¹, and Chusni Ansori³

¹Geological Engineering Department, Faculty of Engineering, Universitas Gadjah Mada, DI Yogyakarta, Indonesia

²Unconventional Geo-resources Research Group, Faculty of Engineering, Universitas Gadjah Mada, DI Yogyakarta, Indonesia

³Research and Development Division for Earth Conservation and Information, Indonesian Institute of Sciences, Central Java, Indonesia

Abstract. Scandium (Sc) is important element for its utilization in modern industry. Initial Sc content in the parent rocks primary importance controlling the Sc concentrations in its weathered derivatives. This contribution examines the Sc concentrations in parent rocks of mafic and ultramafic rocks related to the ophiolite series in Luk Ulo Complex, Karangsambung, Central Java, Indonesia. The ophiolite series in this area are basalt, microgabbro, gabbro, websterite, and serpentinite from 5 locations of Medana, Lokidang, Parakansubah, Selogiri, and Pucangan areas. The general trend from the distribution of Sc in the ophiolite sequence of Medana and Parakansubah-Lokidang Rivers suggests the Sc contents increase from shallow to deeper levels of the sequence. The lowest concentrations of Sc in the ophiolite sequence of Medana and Parakansubah-Lokidang Rivers are in basalt, which are 24–29 ppm. In the middle sequence, the Sc concentrations are 27–34 ppm and 24–43 ppm, respectively in microgabbro and gabbro. The highest Sc concentrations are in websterite, which are 51–54 ppm, as the deepest sequence of the ophiolite in this area. Meanwhile, Sc contents in serpentinite from Selogiri and Pucangan areas are 5–11 ppm, which are considered the lowest Sc contents. It suggests that the pre-serpentinization mineral composition rather than the process of serpentinization determine the elemental abundance of Sc in serpentinite. The results are used to be an analog for Sc identification in the ophiolite belts in central Indonesia. This also considering that Luk Ulo Complex been established as National Geopark of Karangsambung-Karangbolong, so that mining activities are prohibited in this area.

1 Introduction

Scandium (Sc) is the 21st element and part of the Group 3 metals in the periodic table. Sc therefore can be classified into the rare earth elements (REE). Currently REEs and yttrium are designated jointly as REY. The REY has several remarkable applications for the modern industry e.g. wind power generators, electric vehicles, and light-emitting diodes [1]. Owing its usefulness, there are significant growths for REY in the global demand forecasting in future. Particularly in leading-edge technologies of the energy and environmental fields, Sc has increase number of attention for its application. For example, Sc-reinforced aluminum alloy that light, strong, and thermally resistant are used to make lightweight automobiles, high quality sports equipment, and aerospace industry [2].

Sc resources are mainly produced by product of other commercial elements such as iron ores in Russia and Ukraine; tantalum, aluminium and zirconium ores in Australia; iron, tin and tungsten ores in China [3, 4]. In Mongolia (Bayan Obo), Sc is mainly hosted by aegirine, which are concentrated mostly in bastnäsite, monazite,

and xenotime (26–110 ppm) [1]. Sc-rich occurrences with economically grades have been identified in some oxide-rich laterites weathered derivative of mafic and ultramafic rocks [5, 6]. The Sc enrichment is interpreted resulting from the intense leaching of mobile cations during lateritization of the parent rocks. Therefore, the initial Sc contents of the parent rocks are primary importance controlling the Sc concentrations in its weathered derivatives [2]. The Sc can concentrated at 100–400 ppm in the laterites derived from the intense weathering of ultramafic and mafic rocks [5]. In some places can reach up to 800 ppm, by incorporation process into the hematite crystal structure or adsorption on goethite [5]. Recently, high-grade Sc laterite (>300 ppm), located in New South Wales, Australia, has been identified and is under development for exploitation [5].

Ultramafic rock are mostly derived from earth-mantle origin. This rock, within the ophiolite suite (oceanic crust: ultramafic, mafic, and deep sea sedimentary rocks), were occupied approximately 3 million hectare in Indonesia, which spread sporadically in Aceh until Papua. In this present study, we determined

* Corresponding author: nugroho.setiawan@ugm.ac.id

Fig.1. Geological map and sampling location of research area in Luk Ulo Complex. Modified from [11].

the abundant of Sc in the parent rocks of mafic and ultramafic rocks part of the ophiolite sequence in the Luk Ulo Complex, Karangsambung, Central Java. The result of this studies have led to conclusions the distribution of Sc in the ultramafic and mafic rocks in the ophiolite sequences in the Luk Ulo Complex, Karangsambung, Central Java.

Furthermore, the results are used to be an analog for Sc identification in the ophiolite belts in central Indonesia (Meratus Complex, South Kalimantan; Pompangeo Complex, Central Sulawesi) as they might be derived from similar ages of oceanic crust [7, 8, 10]. Another stronger reason is Luk Ulo Complex has been established as National Geopark Karangsambung-Karangbolong. Therefore, mining and exploitation activities are prohibited in this area.

2 Regional Geology

Cretaceous accretionary complexes are sporadically exposed in the central Indonesian region throughout Java, Kalimantan and Sulawesi (e.g. [7, 8]; Fig. 1). The accretionary deposits consist of subduction related rocks including ophiolite and metamorphic rocks. Ophiolite is a series of rocks derived from oceanic crust and upper mantle in which includes of deep-sea sediments, basaltic pillow lava, dolerite, gabbro, and ultramafic rocks, respectively from upper to bottom parts [9].

These rocks are significantly exposed in Luk Ulo Complex, Karangsambung area, Kebumen, Central Java [10, 11]. The ophiolite rocks in the Luk Ulo Complex were part of the mélangé units. The mélangé formation consists of shale, sandstone, chert, mafic rocks, ultramafic rocks, limestone, conglomerate, and metamorphic rocks [11]. Tectonic slices of the complex have a trend of ENE–WSW [11]. Northern part of the complex is dominated by metamorphic blocks including

high-pressure metamorphic rocks [12]. Southern part of the complex is dominated by ophiolite rocks in which some of them were experienced serpentinization [10, 13, 14]. These ophiolite rocks well exposed along the Medana, Lokidang, and Parakansubah Rivers [12, 13]. Furthermore, there are 5 major locations of ultramafic rocks outcrop in Luk Ulo Complex [15], which are Selogiri, Medana, Parakansubah, Lokidang, and Pucangan Areas (Fig. 1).

Ages of the complex based on the high-pressure metamorphic rocks yielded 117–119 Ma (Rb–Sr of eclogite and epidote amphibolite) [15]. The ages of the ophiolites were suggested 81–85 Ma (K–Ar; [10]). Furthermore, Wakita et al. [16] confirmed this Cretaceous ages of the ophiolite from fossils on radiolarian chert.

3 Methods

Fieldwork was done in the Luk Ulo Complex to collect rock samples of mafic and ultramafic rocks related to the ophiolite series from 5 different locations. The locations are Selogiri, Medana, Parakansubah, Lokidang, and Pucangan (Fig. 1). Spot sampling was conducted in Selogiri and Pucangan areas, which collected 9 samples of serpentinites from these areas. In Medana, Parakansubah, and Lokidang areas, rock samples were collected from river bedrock. Geographically, Parakansubah and Lokidang Rivers are considered to be one river flow, which Parakansubah is in the upstream (Fig.1). Totally 9 samples were collected from both rivers. Meanwhile, 6 rock samples were collected from along the Medana River.

The rock samples were observed their texture and mineralogical composition by petrographical analyses. Based on its rock types, mineral composition and least

Fig. 2. Bedrock lithologies along the Medana (A), Parakansubah (B) and Lokidang (C) Rivers.

weathered or altered conditions, 24 samples of mafic and ultramafic rocks were selected to determine their Sc and other REY concentrations by geochemical analyses. REY and Sc concentrations on whole rocks were determined by lithium borate fusion combined with fused bead and acid digestion using ICP-MS and ICP-AES in commercial laboratory ALS Canada.

4 Results

4.1 Field Observations and Rock Sampling

4.1.1 Medana River

Ophiolite sequence crops out as river bedrock in Medana River. Medana River extends approximately 5.37 km with flow direction from North to South (Figs. 1 and 2a). In some areas, river valleys have maximum height of 10–15 m. This thickness made from the weathering profile of the ophiolite rocks. The ophiolite sequence, which consists of chert, basalt, microgabbro, and gabbro, was identified in this river (Figs. 3a–c). The deeper level of the ophiolite sequence crops out in the northern part or in the upstream of the river (Fig. 2a). The outcrops show intense ductile deformation and mylonitization. However, no ultramafic rocks expose in this river. Totally 6 rocks samples of mafic rocks were collected from this river (Table 1).

4.1.2 Parakansubah and Lokidang Rivers

Geographically, Parakansubah and Lokidang Rivers are one river flow with the Parakansubah as the upstream (Fig. 1). Total length of these both rivers approximately 8.32 km (Figs. 2b and 2c). The ophiolite sequence from shallow to deep level, which consists of chert, basalt,

microgabbro, gabbro, and ultramafic rocks, were identified in these rivers as bedrock outcrop (Figs. 2b and 2c). The outcrops show intense ductile deformation and mylonitization. Particularly in Parakansubah River, contacts between lithologies are identified as a complex fault. Contrasting to the Medana River, ultramafic rocks were identified in this area as tectonic blocks surrounded by serpentinite (Fig. 3d). The ultramafic rocks are websterite and olivine websterite (Table 1). Totally 8 samples of mafic and ultramafic rocks were collected from these rivers (Table 1).

Fig. 3. Mafic and ultramafic rocks crop out as river bedrock in Medana (A, B, C), Parakansubah and Lokidang Rivers (D).

4.1.3 Selogiri and Pucangan Areas

In Selogiri and Pucangan areas, rock samples were collected from the outcrop in road cut or forest area. The outcrops show intense ductile deformation and mylonitization. Most of the samples were experienced

Table 1. Mineral composition of mafic and ultramafic rocks from Luk Ulo Complex.

No	Sample No.	Rock Type	Location	Mineral Assemblages									
				Primary minerals					Secondary Minerals				
				Pl	Cpx	Opx	Ol	Opq	Atg	Ctl	Chl	Clay	Tlc
1	KP-01	Serpentinite	Selogiri	–	–	–	–	◆	Δ	○	◆	–	–
2	KP-02	Serpentinized Harzburgite	Selogiri	–	–	◆	□	◆	Δ	◆	◆	–	–
3	KP-04	Serpentinized Websterite	Selogiri	–	◆	◆	–	◆	○	□	–	○	–
4	KP-05	Serpentinite	Selogiri	–	–	–	–	◆	Δ	○	◆	□	◆
5	KP-06	Altered Serpentinite	Selogiri	–	–	–	–	□	◆	◆	–	Δ	□
6	KP-08A	Altered Serpentinite	Selogiri	–	–	–	–	□	◆	◆	–	Δ	□
7	KP-10	Serpentinite	Selogiri	–	–	–	–	◆	Δ	○	–	–	–
8	KP-11	Serpentinite	Pucangan	–	–	–	–	□	Δ	□	–	○	–
9	KP-12	Serpentinite	Pucangan	–	–	–	–	–	Δ	□	□	Δ	–
10	LKD-01	Basalt	Lokidang River	Δ	○	◆	□	◆	–	–	○	◆	–
11	LKD-08A	Micro-gabbonorite	Lokidang River	○	○	◆	–	◆	–	–	□	□	–
12	LKD-14	Micro-gabbonorite	Lokidang River	Δ	○	□	–	◆	–	–	○	–	–
13	LKD-24	Gabbonorite	Lokidang River	Δ	○	◆	–	◆	–	–	□	–	–
14	LKD-26B	Micro-gabbonorite	Lokidang River	Δ	□	◆	–	◆	–	–	○	□	–
15	PKS-05	Olivine Micro-gabbro	Parakansubah River	Δ	○	–	◆	◆	–	–	□	–	–
16	PKS-14B	Olivine Websterite	Parakansubah River	–	Δ	○	□	◆	○	–	–	–	–
17	PKS-18A	Websterite	Parakansubah River	–	Δ	○	–	◆	○	–	–	–	–
18	PKS-25	Gabbonorite	Parakansubah River	Δ	○	○	–	◆	–	–	◆	–	–
19	MED-01	Basalt	Medana River	Δ	○	◆	–	◆	–	–	□	□	◆
20	MED-03	Basalt	Medana River	Δ	○	◆	◆	◆	–	–	○	◆	–
21	MED-07	Micro-gabbonorite	Medana River	Δ	Δ	–	–	◆	–	–	□	–	–
22	MED-17	Gabbonorite	Medana River	Δ	Δ	□	–	◆	–	–	◆	–	–
23	MED-19	Gabbonorite	Medana River	Δ	Δ	□	–	◆	–	–	◆	–	–
24	MED-20	Gabbonorite	Medana River	Δ	Δ	◆	–	◆	–	–	□	–	–

Δ Abundant; ○ Rich; □ Moderate; ◆ Rare; – Not present

serpentinization. Relict textures of ultramafic or mafic rocks were identified under the polarization microscope as an assumption of their protolith (Table 1). Totally 9 samples of serpentinites were collected from these area (Table 1).

4.2 Ophiolite Series in Luk Ulo Complex

The ophiolite series in Luk Ulo Complex were determined from the outcrop sequence of Medana, Parakansubah and Lokidang Rivers. The shallow to deep level of the ophiolite were identified from south to the northern part of the Rivers (Fig. 3), which are chert, basalt, microgabbonorite, gabbonorite, and websterite (Fig. 4). However, some contacts of each lithology remain unclear and mostly caused by fault contact. Therefore, ideal section of ophiolite (e.g. Semail, Oman; [9]) could not be observed in the Luk Ulo Complex.

Total thickness of the ophiolite in Medana River at least 1.57 km consists of basalt (0.52 km), microgabbonorite (0.65 km), and gabbonorite (0.40 km; Fig. 4a). This thickness is considered as minimum thickness in this area, as several outcrops still could not be identified because of highly weathered or located deep inside forest. In Parakansubah-Lokidang Rivers,

total thickness of ophiolite at least 5.18 km, which consist of basalt (1.10 km), microgabbonorite (1.56 km), gabbonorite (1.60 km), and serpentinite (0.92 km; Fig. 4b).

Fig. 4. Sc and REY concentrations in ophiolite sequence from Medana (A) and Parakansubah-Lokidang (B) Rivers.

4.3 Sc Composition in Ophiolite Series

The mafic and ultramafic rocks of ophiolite were identified their Sc and REY compositions (Tabel 2). Sc and total REY were plotted in the ophiolite sequence of Medana and Parakansubah-Lokidang Rivers to identify their characteristics based on their ophiolite profile (Fig. 4). Sc and REY contents in basalt from Medana River ranging from 28–29 ppm and 77.67–81.83 ppm, respectively from 2 samples (MED 01 and MED 03). Basalt from Parakansubah-Lokidang Rivers has Sc and REY contents of 24 ppm and 142.86 ppm, respectively from 1 sample (LKD 01).

Microgabbriorite from Medana River has Sc and REY contents of 30 ppm and 104.97 ppm, respectively from 1 sample (MED 07). Four microgabbriorites (LKD 08A, LKD 14, LKD 26B, PKS 05) from Parakansubah-Lokidang Rivers have Sc and REY ranging from 27–34 ppm and 86.3–110.97 ppm, respectively. Gabbriorites from Medana River have Sc and REY contents ranging from 32–39 ppm and 51.95–73.81 ppm, respectively from 3 samples (MED 17, MED 19, MED 20). While gabbriorites from Parakansubah-Lokidang Rivers have Sc and REY contents ranging from 24–43 ppm and 45.87–66.91 ppm, respectively from 2 samples (LKD 24 and PKS 25). Ultramafic rock (websterite), which only observed in Parakansubah River, has Sc and REY contents ranging from 51–54 ppm and 56.09–58.3 ppm, respectively from 2 samples (PKS 14B and PKS 18). Meanwhile, serpentinites in Pucangan and Selogiri areas have Sc and REY contents ranging from 5–11 ppm and 7.67–18.35 ppm, respectively from 9 samples (KP 01, KP 02, KP 04, KP 05, KP 06, KP 08A, KP 10, KP 11, and KP 12; Table 2, Fig. 5).

Fig. 5. Sc and REY compositions in serpentinites from Selogiri and Pucangan areas.

5 Discussions

The initial Sc content of parent rocks represents the important control on the maximum Sc grades in their lateritization. The example of lateritization of Sc-rich clinopyroxenites resulted in a 4 to 10 folds increase of the Sc concentration, which can elevated the Sc grades

(300–600 ppm and up to 800 ppm) in Australia [5]. Comparing to other ophiolite complex in Indonesia region, up to recent date only ultramafic rocks from Sorowako, South Sulawesi had been reported their Sc concentrations [6]. Ultramafic rocks in Sorowako area are divided into 2 areas of Patea and West Block, which have bedrock origin of harzburgite [6]. The Sc concentrations at limonite layer in these areas were reported up to 80 ppm [6].

From this study results in Luk Ulo Complex, minimum Sc concentration is 5 ppm, which is in the serpentinite from Pucangan area. Meanwhile, maximum Sc concentration is identified in websterite from Parakansubah River, which has concentration of 54 ppm. General trend from the distribution of Sc and REY versus ophiolite sequence in Medana and Parakansubah-Lokidang Rivers can be seen in Fig. 4. To the deeper level of ophiolite, the Sc concentrations relatively increase. The lowest concentrations of Sc are identified in the shallowest level of ophiolite sequence, which are 24–29 ppm in basalt. Below basalt horizon are microgabbriorite, which has Sc concentrations of 27–34 ppm. Followed by gabbriorite, which has Sc concentrations of 24–43 ppm. The deepest level of ophiolite sequence is websterite, which has Sc concentrations of 51–54 ppm (Fig. 4).

Total REY contents are contradictory with the general trend of Sc concentrations (Fig. 4; Table 2). The total REY relatively decrease from the shallow (142.86 ppm in basalt) to the deeper levels (45.87 ppm in gabbriorite) of ophiolite sequence in Luk Ulo Complex (Fig. 4). Furthermore, the Sc and total REY contents in serpentinites having the lowest concentrations (Sc 5–11 ppm, REY 7.67–18.35 ppm; Fig. 5) compared to the mafic and ultramafic rocks.

The high contents of Sc in websterite might have possibility made by substitution of Sc and Mg in clinopyroxenes as they have very similar ionic radii (74.5 and 72 pm in 6-fold coordination) and electronegativities (1.36 and 1.31), respectively [16]. In this study, the Sc in serpentinite was identified as the lowest contents among other rock types. However, we could not conclude that these lowest contents are resulted from the serpentinization processes. Samson and Chassé [17] and Teitler et al. [2] suggest degree of serpentinization does not affect the whole-rock Sc content in mafic or ultramafic rocks. This suggestion is in agreement with our result that the clinopyroxenes relict bearing serpentinites (KP 04 and KP 05; Table 1) having slightly higher content of Sc compared with other serpentinites (Fig. 5). It appears that the pre-serpentinization mineral composition rather than the process of serpentinization determine the elemental abundance of Sc in serpentinite.

6 Conclusions

Based on the field observation, the weathering profile of mafic and ultramafic rocks in the Luk Ulo Complex can reach up to 10 m thickness. In the laterite horizon of limonite, Sc can also be absorbed on goethite that can

Table 2. Sc and total REY concentrations in mafic and ultramafic rocks from Luk Ulo Complex

Locality		Medana						Lokidang-Parakansubah					
Rock Type		Basalt		Micro-gabbronorite	Gabbronorite			Basalt	Microgabbronorite				Gabbro-norite
Sample No.	Unit	MED 01	MED03	MED 07	MED 17	MED 19	MED20	LKD 01	LKD 08A	LKD14	LKD 26B	PKS 05	LKD24
Sc	ppm	28	29	30	39	31	32	24	34	31	30	27	43
ΣREY	ppm	77.67	81.93	104.96	70.77	73.81	51.95	142.86	110.97	96.24	88.11	86.3	66.91

Locality		Lokidang-Parakansubah			Selogiri-Pucangan								
Rock Type		Gabbro-norite	Websterite		Serpentine								
Sample No.	Unit	PKS 25	PKS18	PKS 14B	KP01	KP02	KP04	KP 05	KP 06	KP08A	KP 10	KP 11	KP012
Sc	ppm	24	54	51	10	10	13	11	7	8	10	5	7
ΣREY	ppm	45.87	58.3	56.09	10.59	13.38	14.43	14.17	7.82	9.11	18.35	11.19	7.67

contains 10 times the Sc concentrations of the parent rocks [2, 5]. Sc also substitutes Fe^{3+} in hematite crystal structure for the residue of goethite mineralization [5]. The Sc concentrations in limonite layer of the Luk Ulo Complex might have possibility reach up to 50 ppm as the concentration tend to be enriched from the intense weathering of parent bedrocks. Therefore, the Sc content on laterite and their product derivative in Luk Ulo Complex need further attention in future studies. Furthermore, Sc also substitutes Mg in garnet and amphibole, which are present in garnet- and amphibole-bearing metamorphic rocks that also crop out in this area [7, 8, 15].

The Luk Ulo Complex been established as National Geopark of Karangsambung-Karangbolong, so that mining and exploitation activities are prohibited in this area. However, the study of Sc in this area should be continue for the sake of geoscience and to be used as geodatabase and comparison of other ophiolite belts and ultramafic terranes in Indonesia.

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